VIBRATION STUDY OF MAGNETORHEOLOGICAL FLUID FILLED SANDWICH BEAMS

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Abstract – The concept of vibration mitigation in flexible structures using smart fluids has attracted researcher's interest in the last few years. Significant research work has been done on the structures with electrorheological fluids, but there has been a little work with the magnetorheological fluids. This study investigates the vibration controllability of MR fluid filled cantilever beams under externally applied magnetic fields. The adaptive structures were fabricated by adding a MR fluid layer between the adjacent elastic layers and the properties of two different types of sandwich beams were studied. In the first type, free and forced vibration responses of aluminium beam with partial treatment were evaluated and compared with fully filled beam. The controllability of vibration response was observed in terms of variations in vibration amplitudes and shifts in magnitudes of the resonant natural frequency. In second type, a composite cylindrical sandwich cantilever beam with end plate was fabricated. It consisted of outer stainless steel hollow pipe with end mass, inner wooden rod and an embedded MR fluid. Inner rods with different diameters were used to vary the thickness of MR fluid layer. Forced vibration response of such beams exhibited increased damping under increased magnetic fields.

***Keywords** - magnetorheological fluids; MR sandwich cantilever beams; permanent magnets; natural frequency; vibration amplitudes.*

I. INTRODUCTION

In the systems having mechanical vibrations, amplitudes may range from a few nanometers to meters depending upon the type of the system. Detrimental effects of vibrations can be categorized as system failure, discomfort and operational inefficiencies. Structural vibrations can be reduced in different ways; the most common are stiffening, damping and isolation. Primary objective of the present study is to provide vibration mitigation device in the form of a cantilever beam whose stiffness and damping properties can be tuned by means of MR fluid effect. MR fluids are the colloidal suspensions which can change from liquid to quasi-solid phase under the influence of external magnetic field. Small sized, magnetizable, ferrous particles contained in the low permeability oil constitute a MR fluid. When subjected to external magnetic field, these particles are attracted to each other and form chain like and columnar structures in the direction of applied magnetic field and the phase changes from liquid to solid. When external field is removed the phase again changes to liquid. [1, 2] This behavior of MR fluid is linked with structures. The quick response, good reversibility and controllable performance of MR fluids make them suitable for use in various devices. [3]

Use of smart fluids for structural vibration minimization was the main focus of research in the last few years. However, focus on adaptive structures using ER fluids was more as compared with MR fluids.

Vibration response of ER fluid filled cantilever beams were investigated theoretically and /or experimentally by many researchers. [4-8]

Also research was done with partially treated ER beams with different sized volumes of ER fluids. [9] Similarly, partially filled beams were tested in different regions [10] to evaluate the vibration controllability. However, ER fluids exhibit certain shortcomings such as low yield strength, requirement of high voltage and greater sensitivity to common impurities. [11] On the other hand, MR fluid offers higher yield stress [12] under the influence of magnetic field. Studies have shown that MR fluid is very suitable for higher bandwidth control through rapid changes in its rheological properties under varying magnetic fields.

Very few literatures are available on MR fluid application in adaptive sandwich structures. Yalcintas and Dai [13, 14] analyzed the dynamic responses of a MR fluid adaptive structure using the energy approach and compared the responses with those of a structure employing ER fluid. Sun et al. [15] analytically investigated the dynamic responses of a MR sandwich beam using an energy approach and compared the results with the measured data. The results of these investigations recommended use of MR fluid for higher degree of controllability. However some of these studies encountered problems like beam bending, fabrication complexity and improper magnetic fields.

The objective of this work is to present vibration controllability of cantilever beams with different configurations and materials which are fabricated by simple and economical processes and also with readily available cheaper material.

II. DESIGN AND MANUFACTURE OF MR SANDWICH BEAMS

In this study two different types of cantilever beams were fabricated as simple mechanical models to evaluate the performance of sandwich adaptive structures. The details of fabrication of each type of beam are explained in the following sections.

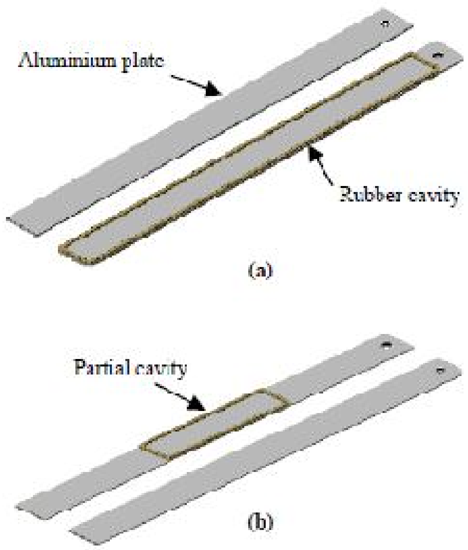

Fig. 1. Arrangement of aluminium beams

a. Fabrication of aluminium sandwich beam

In this category, further, two configurations viz. fully filled and partially filled beams were prepared. A fully filled aluminium beam consisted of two elastic aluminium strips (300 mm x 24 mm x 2 mm) with zero magnetic permeability. In order to maintain a uniform gap of 2 mm and contain the fluid in between the top and bottom layers, high strength rubber of 2 mm thickness and 1.5 mm width was applied around the edges using an adhesive. The arrangement of strips prior to gluing is as shown in Fig. 1a. The strips were glued and sealed to avoid any leakage. For filling the MR fluid in the cavity, a small hole of 1 mm diameter was drilled in each side of the beam. From one end, MR fluid was injected by using a hypodermic syringe. This allowed air bubbles to escape from the hole on the other side. Finally, the two holes were sealed and allowed to dry. Commercially available ‘Rapid Fevitite’ was used for gluing and sealing. In this study, three different MR fluids were prepared with 22%, 32% and 41% iron particles volume fraction, respectively. Iron particles of average size 50 micron were used to improve the magnetic affinity. The preparation cost of the fluid was almost 1/10th as compared to the commercially available fluids. These MR fluids were tested to find their magnetic induction and flux density values. MR fluid with 32% iron particles produced better results and hence it was decided to use this configuration for filling into the beams.

Similarly, for the partial treatment, a central cavity of 100 mm length was prepared with the same material and aluminium was located at the remaining portion of the mid- layer as shown in Fig. 1b.

b. Fabrication of composite cylindrical sandwich beam

This type of beam consisted of an outer stainless steel hollow pipe with end plate, inner wooden rod and an embedded layer of MR fluid. The stainless steel pipe was cut to a length of 350 mm from a long seamless pipe of outer diameter 19 mm and thickness 1 mm. The pipe was brazed to a plate of mild steel having two holes for fastening on a rigid frame. Wooden rods of three different diameters – 16 mm, 15mm, and 14 mm were machined to a length of 345 mm. Two steps of 17 mm, and 20 mm diameter were provided on each wooden rod for press fitting into the stainless steel pipe. The arrangement of the composite beam is as shown in Fig. 2.

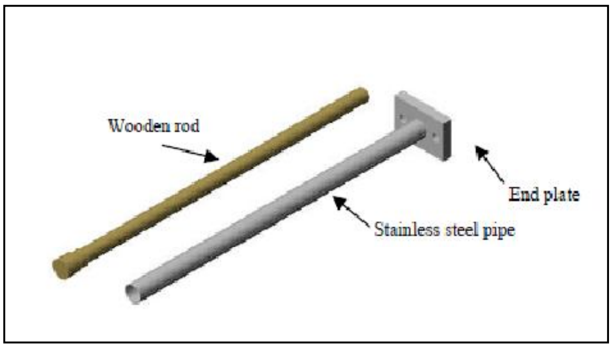

Fig. 2. Arrangement of composite cylindrical beam

Table I shows general properties of the material used for fabrication of these beams.

III. EXPERIMENTAL SETUP

Various devices used for conducting the experiments included – a rigid frame for mounting cantilever beam, permanent magnets, an amplifier, oscillator, exciter, accelerometer, data acquisition system and dynamic signal analyzer. Permanent magnets of circular shape with high power were used to generate magnetic field. A Guass meter produced by PISCO company (model DGM-102) was used to measure magnetic field intensity. Two rows of magnets were formed at the top and bottom side of the beam, by fastening the magnets to adjustable aluminium square pipes which in turn were attached to a rigid frame. Magnetic field intensities were varied by varying the distance between the rows of magnet and by adding or removing magnets from the rows. A schematic of the experimental setup is presented in Fig. 3.

For application of forced vibrations, exciter (model ID-230) with a capacity to produce 200 N peak sine force and maximum displacement of 12 mm peak to peak along with function generator produced by the company Instrol devices was used. The exciter was driven by power amplifier and oscillator which generated sinusoidal signals in the frequency range from 1Hz to 10 kHz. The accelerometer was installed on the free end of the beams. A dynamic signal analyzer was used to acquire and process input/output signals with the NVgate software.

The vibration response was obtained in terms of natural frequencies and vibration amplitudes as output results.

TABLE I : MATERIAL PROPERTIES

Material	***Density(r) (kg/m³)***	***Young's modulus (E) GPa***
Aluminium	2710	70
Stainless Steel	7480	193
Wood	420	11
MR fluid	3000	--

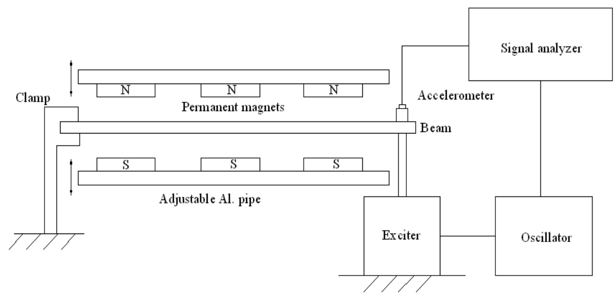

Fig. 3 (a) Block diagram of experimental setup

IV. RESULTS AND DISCUSSIONS

Initially, tests were conducted on aluminum beams to find the free and forced vibration response in terms of natural frequency and vibration amplitudes under different magnetic field intensities. Later, the vibration response of composite cylindrical sandwich beam was studied. The results obtained for the various cases are discussed in the following sections.

A. Free vibration response of fully filled aluminium beam

The beam was displaced from the equilibrium position by 25 mm and released immediately to initiate damped free vibrations. Response curves were obtained for 0 G, 300 G and 550 G. It was observed that under the increased magnetic fields, peaks of vibration amplitudes were decreased. At 0 G, damping ratio (ζ) was 0.11 and when field was increased from 300 G to 550 G, damping ratio (ζ) increased from 0.18 to 0.22. The rate of decay of vibration (δ) and the damping ratio (ζ) were calculated from the following equations.

$$\delta = (1/n).\ln [x_1/x_{n+1}] \quad (1)$$

$$\zeta = \delta/2\Pi \quad (2)$$

where δ corresponds to logarithmic decrement, x is the vibration amplitude and n is the number of cycles.

B. Forced vibration response of fully filled aluminium beam

The beam was excited by the exciter without applying any magnetic field. The vibration amplitudes were observed for different values of frequencies. When 250 G field was applied at the clamped end, the natural frequency shifted to higher value and also vibration amplitude slightly to a higher value. Further, when the field was increased to 500 G, amplitude reduced. For the same value of magnetic field and location at free end, the natural frequency shifted to a lower value. Fig. 4 shows the vibration response curves for different magnetic field intensities at clamped and free ends.

C. Forced vibration response of partially filled aluminium beam

This beam was also tested under varying magnetic field intensities. Fig. 5 presents the vibration spectra.

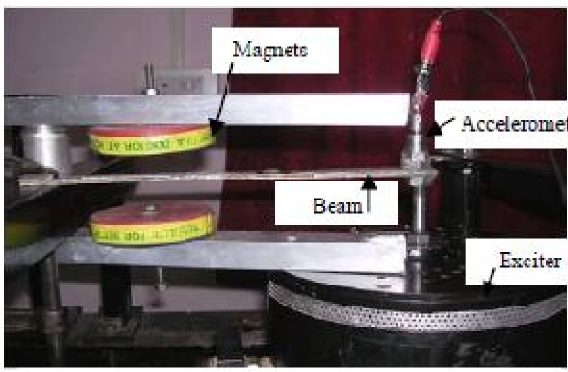

Fig. 3 (b) Photograph of experimental setup

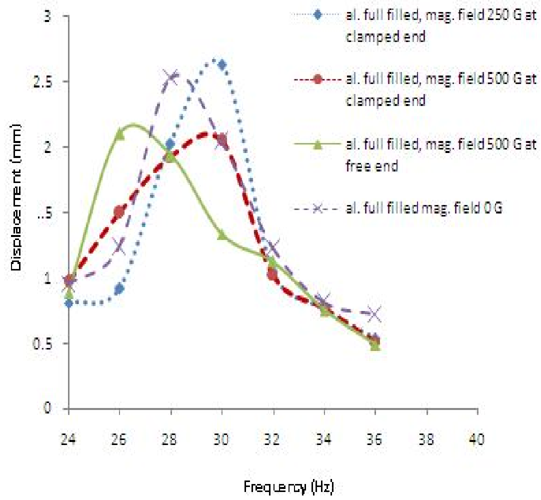

Fig. 4 : Vibration spectra for fully filled beam

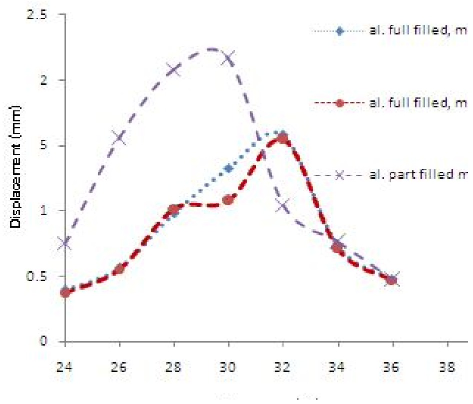

Fig. 5 Vibration spectra for partially filled beam

It was observed that a partially filled beam exhibited considerable damping as compared to fully filled beam. The frequency shift capability was similar.

D. Forced vibration response of composite cylindrical sandwich beam

Different configurations of this type of beam were tested for observing the effect of thickness of MR fluid on damping. It was observed that there was no change in the natural frequency under the influence of varying magnetic field intensities. When 16 mm wooden rod was replaced by 15 mm rod, vibration amplitudes were increased (for other conditions being kept same).

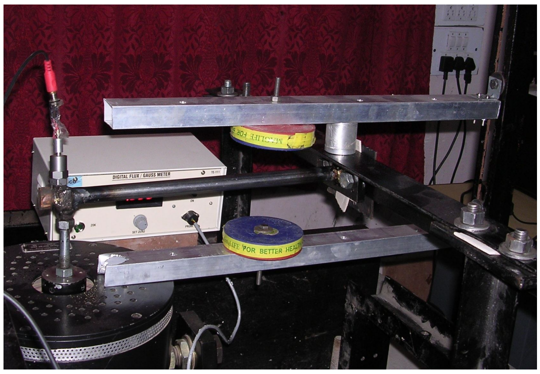

Fig. 6 Photograph of experimental setup of cylindrical composite beam

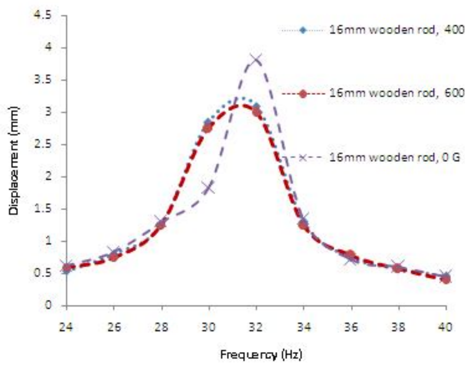

Fig. 7 Vibration spectra for composite cylindrical sandwich beam with 16 mm wooden rod

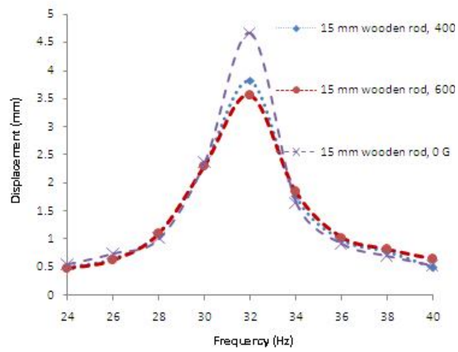

Fig. 8 Vibration spectra for composite cylindrical sandwich beam with 15 mm wooden rod

Fig. 6 shows the experimental setup for testing of composite cylindrical sandwich beam. Vibration spectra for composite cylindrical sandwich beam with 16 mm wooden rod and 15 mm wooden rod are shown in Fig. 7 and Fig. 8 respectively.

Similar vibration spectra were observed for 14 mm wooden rod configuration. Such type of configurations proved to be useful in the applications where significant damping is required.

V. CONCLUSIONS

In this paper, vibration controllability of MR fluid filled sandwich beams was studied. Stiffness and damping characteristics of fully filled and partially filled aluminium beams were investigated. Free and forced vibration response of fully filled beam was studied under the influence of varying magnetic field intensities applied at different locations. Partially filled aluminium beam was studied under forced excitations. Also, different configurations of composite cylindrical sandwich beams were tested under forced vibrations. The effect of varying MR fluid thickness was studied in this case. The observed vibrations characteristics of these beams are summarized as follows:

1. In the free vibration study, damping ratio of fully filled aluminium beam increased by 11% under increased magnetic field.
2. Frequency of fully aluminium filled beam shifted by 6.6% and damping improved under increased magnetic field. For different locations of magnetic fields, frequency shifted in the band of 13.33%.
3. Partially filled aluminium beam showed similar frequency shift capability with high damping effect.
4. Composite cylindrical sandwich beams showed effective damping performance.

Future work may be done in order to study the stiffness and damping properties of MR fluid filled sandwich beams with different materials, configurations and boundary conditions.

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